

Appendix G: Construction & Demolition Waste (C&DW) modelling

G.1. Introduction

This document provides an overview of construction and demolition waste (C&DW) and sets out the assumptions and detailed modelling done to estimate figures for waste arisings and disposal routes in the report.

G.2. Overview of C&DW

Construction and demolition activities generate significant amounts of waste. Household waste also has an impact (some 30 Mt per year) but it is only one-third of the volume of material generated by the construction and demolition industry (90 Mt). Figure 1 shows the relative importance of different types of activity in the industry. However, these figures are measured in contract value, not in terms of the mass or volume of waste generated.

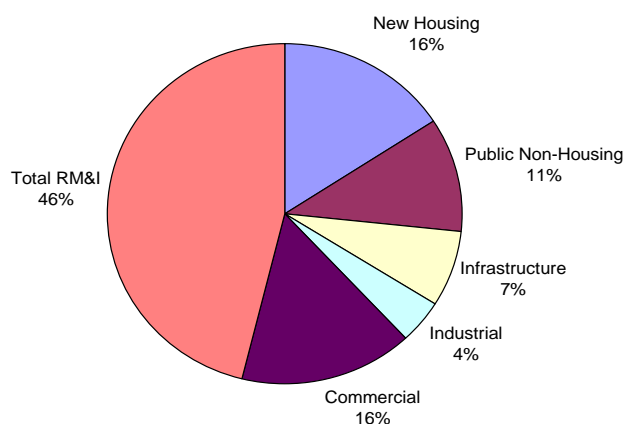


Figure 1 Value of construction industry output by sub-sector, 2004

Source: Construction News Plus website.

Note: RM&I = Refurbishment, Maintenance & Improvement

The DIY market for home improvement amounts to some £5bn per year (Construction News website) and some C&DW, assumed to be about 1% of the total, is disposed of in the household waste stream (Smith *et al* 2002). In terms of monetary value, the DIY market is dwarfed by the £70bn estimated activity in the professional market (Figure 2).

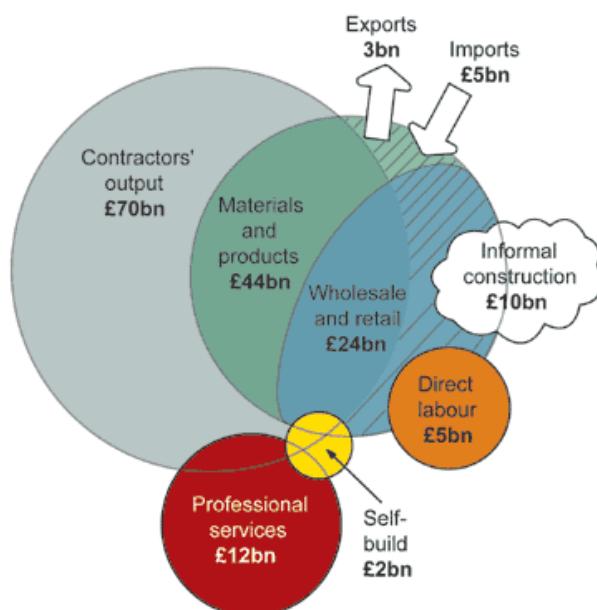


Figure 2 Structure of the construction industry

Note: overlapping circles indicate where one sub-sector contributes to the output of another
Source: Construction News website

Current practices in the construction industry are notoriously wasteful and inefficient. The Construction Industry Mass Balance report (Smith *et al* 2002) estimates resource efficiency in two ways: products created relative to resources required; and additions to the built stock compared to resources required. The figures are 86% and 64% respectively. The difference between the two (22%) is the amount of waste created in the process of turning materials and products into buildings. In construction, 30% of work by value is in fact re-work to eliminate faults and defects. Most faults are caused by process problems, such as poor workmanship and site supervision.

The current level of re-use and recycling in the industry is estimated at 96% in one report (Defra 2003) and 20% in another (Smith *et al* 2002). The wide discrepancy may be due to different interpretations of the large volume of material used to back-fill landfill sites: the decision to designate this activity as 're-use' or 'landfill' is likely to be significant: one estimate is that such material amounts to over 10 Mt (Smith *et al* 2002).

The Government-sponsored Waste Reduction Action Programme (WRAP) publishes good practice guides and case studies demonstrating how simple changes to on-site practices (such as having separate skips for segregating waste at source) can dramatically improve the percentage recovered for recycling and reduce the burden on landfill sites (WRAP website). The current market for reclaimed materials (ie re-use through salvage) is about 3.4 Mt, or 3% of the total, while less than 1% of construction and demolition waste by weight is toxic, requiring special disposal (Smith *et al* 2002).

If the aim were to reduce only waste, then a lower level of construction and demolition activity might seem a wise strategy. However, the issue of construction and demolition waste is closely associated with energy consumption and land use. These are areas where significant benefits can be achieved under one environmental impact (eg energy) but only at an environmental cost elsewhere (eg waste). A strategy of housing renewal has the potential to improve the energy efficiency of the

stock and, through a process of demolition and rebuilding (or conversion of large houses into several flats), to increase the density of housing overall, thereby making good use of previously developed land (PDL) and minimising the pressure on greenfield land. The negative impact in terms of additional waste can be minimised – though not avoided totally – through a number of improvements in waste management practice.

G.3. Modelling results and assumptions

The modelling uses different assumptions for each of the four sub-sectors of waste identified in housing renewal: demolition of homes, construction of new homes, refurbishment of homes, and site excavation as preparation for new construction.

Because of the high levels of uncertainty about input data, no attempt has been made to include a temporal dimension to any of the scenarios. The margins of error on the input variables make such an exercise potentially misleading: data with large annual errors multiplied over 45 years can only give unreliable results. Instead, the modelling for waste from construction and demolition is presented as a comparative snapshot under each of the three scenarios. The relative heights of the bars in figure 3 allow a comparison of the total amount of waste generated in a typical year under the three scenarios. The impact of changing wasteful practices can be seen from the relative fractions of waste going to landfill, recycling and re-use under each scenario.

The three scenarios use the values for new-build, demolition and refurbishment described elsewhere in the report and summarised in table 6 at the end of this appendix. It can be seen from the total height of the three bars in figure 3 that the total amount of waste generated would increase significantly with an accelerated programme of renewal and refurbishment (by some 384% in the case of scenario C).

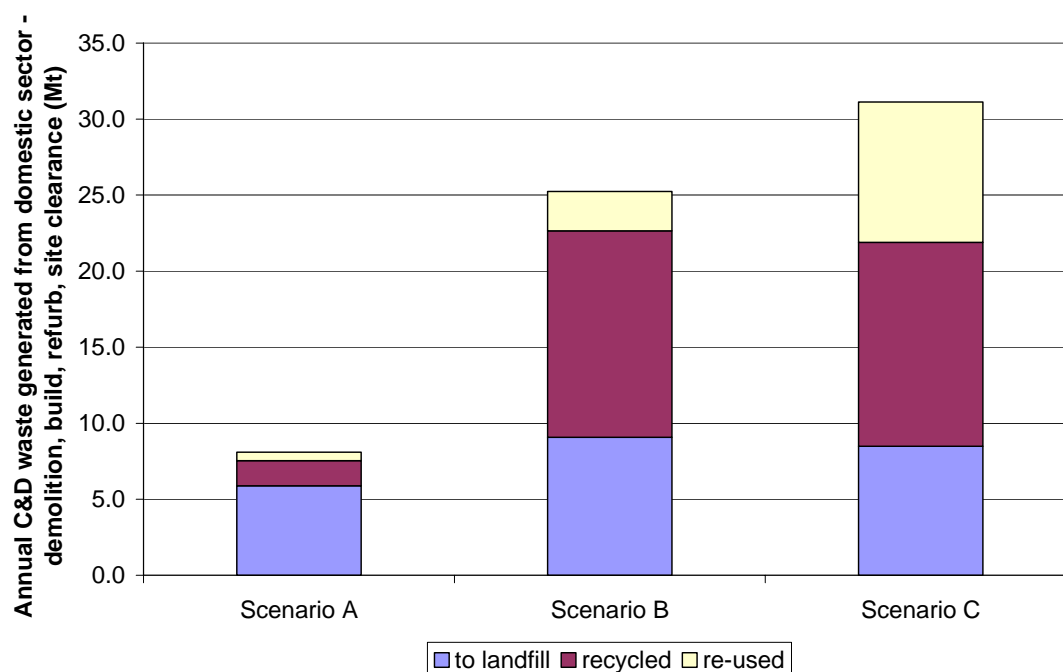


Figure 3 Indicative annual waste disposal quantities and disposal routes, Scenarios A, B & C

G.4. Mass of existing housing

The number of homes demolished in any given scenario is chosen by the modeller, but the mass of existing housing is a real quantity. Estimates for the mass of a single dwelling vary between 60 – 200 tonnes (Jones, pers. comm.). No data could be found for the mass of typical existing dwellings, so these have been modelled for eight dwelling types, using a heroic set of assumptions. The average mass of existing homes is estimated through this process at 76 tonnes, but this model and its assumptions remain a work in progress. A cautious approach is taken here, using a higher estimate of 120 tonnes per dwelling, derived from EcoHomes data (Jones pers comm). The wide range of estimates may be due to one or more of the following:

- Incompleteness/inaccuracy of any of the models
- Data from different countries and/or different dwelling types
- Other authors model typical new homes, which may embody a greater mass of material than the older ones in the ECI model, principally because of an assumption of heavy concrete foundations, but also because of additional materials (eg insulation materials, roofing membranes)
- The highest figures (200 tonnes per dwelling) are for BedZED (Jones pers. Comm.), which is known to incorporate a greater mass of material than typical housing construction in order to reduce operational energy use

G.5. Demolition and waste disposal

ECI estimates of how much material is built into a typical home are based on a disaggregated model of 8 different construction types. Summary descriptions of the 8 dwelling types are given in table 1.

Table 1 Dwelling types used in scenarios with summary details of construction methods and materials.

Dwelling type	Build date	Size	External wall construction	Floor construction	Roof construction
End Terrace	1870s	80 m ² 2 storeys	215 mm brick	Suspended timber	Pitched timber and slate
Mid Terrace	1870s	80 m ² 2 storeys	215 mm brick	Suspended timber	Pitched timber and slate
Semi-detached	1930s	90 m ² 2 storeys	Brick + brick cavity	Suspended timber	Pitched timber and slate
Detached	1850s	104 m ² 2 storeys	215 mm brick	Suspended timber	Pitched timber and slate
Flat (purpose built)	1960s	61 m ² 4-storey building	Brick + block cavity	Concrete slab	Asphalted concrete slab
Flat (converted)	1870s	61 m ² 3-storey building	215 mm brick	Suspended timber	Pitched timber and slate
Tower block	1960s	61 m ² 10-storey building	Steel frame, concrete block in-fill	Concrete slab	Asphalted concrete slab
Four-block	1960s	61 m ² 2-storey building	Brick + block cavity	Concrete slab	Pitched timber and tile

The typical construction of the 8 dwelling types has been modelled in detail to estimate the mass of different materials in each type. A judgement is then made about the mix of disposal routes for these materials under each scenario. The overall percentages of waste re-used, recycled and landfilled are therefore a combination of two factors: the type and mass of materials estimated in existing housing; and a judgement about the direction and success of policies to change waste management practices.

The volume of waste and the management options for dealing with it are in part, at least, dependent on the materials arising from demolition. At least two-thirds of demolition waste by mass is heavy masonry, concrete and brick (Howard 2000). Re-use is a technically feasible option for brickwork in some instances, but not for concrete, which can only realistically be disposed of by recycling or burial in landfill. A key distinction is therefore how much of the proposed demolition involves homes made of brick and homes made of concrete.

Data at this disaggregated level does not exist, so estimates are made combining data from a number of sources. In many cases, numbers are no better than informed guesswork (eg what percentage of bricks from a typical terraced home can plausibly be re-used?). It cannot be emphasised too much that this modelling is really only useful for comparisons of the three scenarios: they give an idea of the relative scale of the environmental impacts and the management options for each – they do not give accurate totals.

The assumptions on waste management practices in the three scenarios are summarised in Tables 2 – 4.

Table 2 Demolition waste model: summary of assumptions on waste management strategies, scenario A

	re-use fraction	recycle fraction	landfill fraction
End Terrace	0.02	0.26	0.72
Mid Terrace	0.02	0.25	0.72
Semi-detached	0.02	0.26	0.72
Detached	0.02	0.26	0.72
Flat (purpose built)	0.00	0.31	0.69
Flat (converted)	0.02	0.31	0.69
Tower block (per flat)	0.00	0.31	0.69
Four-block (per flat)	0.01	0.25	0.74
average	0.02	0.28	0.70

Table 3 Demolition waste model: summary of assumptions on waste management strategies, scenario B

	re-use fraction	recycle fraction	landfill fraction
End Terrace	0.13	0.72	0.14
Mid Terrace	0.13	0.72	0.15
Semi-detached	0.13	0.73	0.14
Detached	0.13	0.72	0.15

Flat (purpose built)	0.07	0.52	0.32
Flat (converted)	0.13	0.74	0.14
Tower block (per flat)	0.02	0.53	0.49
Four-block (per flat)	0.05	0.58	0.48
average	0.10	0.65	0.25

Table 4 Demolition waste model: summary of assumptions on waste management strategies, scenario C

	re-use fraction	recycle fraction	landfill fraction
End Terrace	0.72	0.14	0.14
Mid Terrace	0.71	0.14	0.14
Semi-detached	0.72	0.14	0.14
Detached	0.69	0.16	0.15
Flat (purpose built)	0.18	0.50	0.32
Flat (converted)	0.73	0.13	0.14
Tower block (per flat)	0.00	0.50	0.49
Four-block (per flat)	0.13	0.49	0.48
average	0.48	0.27	0.25

The modelling of demolition waste uses the figure of 120 tonnes of material per dwelling and the average figures for waste management shown in tables 2 – 4.

Reconciliation of the disaggregated figures with national statistics is not possible because the national statistics are not categorised by sector (ie there is no record of whether waste arises from domestic or non-domestic sites). However, the overall figure in scenario A suggests that C&DW from housing contributes 8.1 Mt of waste, or 9% of the total of 90 Mt.

BRE began a new 2-year, DEFRA-funded project in October 2005 to measure waste arisings from construction sites. This data collection exercise would be useful to inform this exercise but the results will be too late for this report.

G.6. Definitions

The development of scenarios for demolition waste follows a waste management hierarchy, in order of preference: re-use – recycle – landfill. Waste reduction is possible in construction and refurbishment work (eg through better site practices and reducing over-ordering), but is assumed not to be a realistic option for demolition (it is impossible to reduce the size of a building that is already there).

Re-use is taken to mean separation of a building element so that it can perform the same purpose (or a very similar purpose) in a new building without substantial processing. So, for example, a wooden beam taken from the roof of a demolished house and re-used as a beam or other structural timber in a new house would be an example of re-use. Another example would be bricks that are removed intact from a building, then cleaned of mortar so that they can be re-used in a new wall. Recycling includes any use of a product which involves substantial re-processing (eg a brick wall that is demolished and crushed for use as aggregate or hard-core). The key difference is that re-use implies a product that remains essentially intact from the time that it is removed from a building to its incorporation into a new structure. In contrast, recycling is typically still an option even if the original product is broken or

otherwise unusable for its original (high-specification) purpose. Occasionally, recycling can result in a product with a higher specification than the original, eg using crushed glass to make glass-fibre insulation. However, such examples of so-called 'up-cycling' are less common than 'down-cycling', where the recycled product has a lower specification than the original.

In the real world, the distinctions are not so clear-cut. A wooden beam is unlikely to be the right length for a new construction so some wastage is to be expected during re-use. Even with the best care taken, not all old bricks will survive de-construction. Off-cuts and other residues from de-construction should follow the waste management hierarchy, with recycling higher than landfill. The scenarios attempt to track these issues by assigning proportions of materials to the categories of re-use, recycling and landfill.

No distinction is made here between disposal with heat recovery and other forms of disposal.

G.7. Scenarios for demolition waste

The model works by assigning a percentage for re-use, recycling and landfill to the different elements of each of the 8 building types in the model. These percentages are in turn derived from a judgement about how re-usable and recyclable each element is in terms of the different material used and their method of assembly. So, a wall made of bricks joined by weak mortar (typical of older housing) is deemed to be technically re-usable, whereas the walls, floors, ceilings and common areas of a concrete-built tower block can be recycled but not re-used. Similar judgements are made about timber, plaster, roof coverings, windows, doors and a host of other materials and products. Other judgements are made about the quantity of material involved, using data from CIBSE design guide A to convert these quantities to masses. For most building elements, totals are given as a mass per square metre (eg for walls) but in some cases it only makes sense to estimate a mass per dwelling, because the element is not closely linked to the total area of wall, floor or roof (eg for gutters and drainpipes). Summary figures for the different scenarios are given in tables 2 – 4 (NB some row totals do not equal 1.0 because of rounding).

Scenario A

It is estimated that about 80% of all C&DW (ie not just demolition waste) goes to landfill and 20% is recycled. The mass of material re-cycled on-site for fill is a potentially large area of uncertainty – the material is not measured but anecdotal evidence from the industry suggests that it is a significant amount (Smith *et al* 2002). Currently promoted good practice guides and case studies tend to mention re-use as the favoured option only in passing, while concentrating most attention on re-cycling (WRAP website). Segregation of waste into separate skips can achieve large improvements in terms of the amount of waste recycled and the reduced burden on landfill. It seems reasonable to infer, therefore, that scenario A might well see an increased level of recycling and reduced level of waste to landfill, but that re-use is not a high priority in actual practice. The existing market for reclaimed materials is some 3.4 million tonnes, or about 3% of the total by mass (Smith *et al* 2002). This is assumed to remain about the same.

Scenario B

The general assumption in scenario B is that current policy initiatives to increase recycling of demolition waste bear fruit in the form of significantly increased rates of

recycling. There is also a large increase in re-use (in relative terms) but the focus is on recycling.

Scenario C

In contrast with scenario B, scenario C assumes that efforts are made to encourage re-use as the least environmentally damaging disposal option for demolition waste. Recycling increases compared with scenario A but to a much lesser degree than in scenario B.

G.8. Scenarios for construction waste

Construction waste accounts for 10 Mt of total UK C&DW, representing 11- 16% of the total, depending on which figure is taken for the total (Smith *et al* 2002, Howard 2000). Sources of waste include packaging, off-cuts of materials, over-ordering of materials and damage to materials due to poor storage and site management. Current practice tends to dispose of all site wastes together and existing good practice guides and case studies show that segregation of waste can reduce the burden on landfill by a significant amount (WRAP website).

Scenario A

In the absence of any data on the amount of waste generated on a house-building site, the volume is estimated to be 12 tonnes per dwelling, which is equivalent to 10% of the total mass figure of 120 tonnes. This figure may be inaccurate, but anecdotal evidence suggests that 10% is a standard rule-of-thumb for over-ordering. Following a similar logic to that set out under 'scenarios for demolition waste' the fractions for disposal routes are:

Re-use	3%
Recycling	27%
Landfill	70%

Scenario B

It is assumed that better management on building sites and more careful ordering reduces the amount of waste per dwelling by 50% compared to scenario A. The emphasis is on recycling, with an assumption that separate skips allow builders to separate waste more effectively than in scenario A. The fractions for disposal routes are:

Re-use	3%
Recycling	57%
Landfill	40%

Scenario C

The amount of waste is assumed to be a 75% reduction compared to scenario A. This is an extension of the same management practices assumed under scenario B, but taken to an arbitrarily higher degree.

As was the case for demolition waste, the emphasis in scenario C is on re-use of construction materials rather than recycling. This means that on-site practices would change in quite profound ways, eg contractors storing off-cuts of timber or long lengths of intact pipes and cables so that this store of off-cuts is exploited first whenever materials are needed. New materials would only be used if no suitable re-used item could be found. The store of re-usable items at the end of one contract

might be transported to the next site to further reduce the quantity disposed of by either recycling or landfill. This would be a time-consuming process and would require a cultural change among several professions, including designers, specifiers of materials and builders on-site. It also has implications for the supply chain, with a new role for brokers of secondary materials supply, matching one site's unused materials with demand from another site in the area. Web-based brokering facilities already exist (eg Salvo website) but the low volumes involved mean that long delivery distances are often involved. To work on the scale implied in scenario C, space would need to be available in every local authority area for secondary materials storage.

Even with such practices in place, the reality is that a significant proportion of the waste material would not be worth keeping to re-use. Recycling is therefore the biggest disposal route here, as in scenario B. The fractions for disposal routes are:

Re-use	10%
Recycling	60%
Landfill	30%

G.9. Scenarios for refurbishment waste

The figures here are for waste associated with improvements for the energy efficiency of the building fabric only. No account is taken of the likely increase/decrease in other kinds of refurbishment, such as fitting new kitchens or bathrooms, even where these have an impact on energy consumption elsewhere, eg for lights and appliances.

The amount of waste generated from a refurbishment project is likely to be highly correlated with the extent and type of work carried out. Current energy efficiency programmes promote measures which are both cost-effective and minimally disruptive (eg loft insulation, cavity wall insulation). More disruptive measures are likely to have a disproportionate effect on the increase in the mass of waste created.

The other variable is the number of energy efficiency refurbishment works undertaken. Recent trends in the annual uptake of loft insulation, cavity wall insulation and double glazing give an overall total of about 1 million interventions per year (Shorrocks and Utley 2003). This rate is assumed for all scenarios, but the volume of waste generated varies. The logic here is to assume that scenarios B and C would involve a move towards more major refurbishments, rather than just a growth in piecemeal activity to install one kind of insulation. By assuming a whole-home approach to energy refurbishments, the number of refurbishment projects may stay the same, but the amount of work done and the mass of waste generated per project would increase.

Scenario A

The typical waste generated is low – 2 tonnes per dwelling refurbished – in recognition of the unambitious programme of refurbishment. The fractions for the various disposal routes are effectively the same as for construction waste, given that the site practices are likely to be the same. They are:

Re-use	3%
Recycling	27%
Landfill	70%

Scenario B

The mass of waste is assumed to be considerably higher at 12 tonnes per dwelling refurbished because of the increased number of disruptive installations – notably wall and floor insulation. The fractions of waste going to the different disposal routes follows the practice for construction waste in this scenario:

Re-use	3%
Recycling	57%
Landfill	40%

Scenario C

With an even higher uptake of disruptive measures than in scenario B, the average mass of waste is assumed to be 30 tonnes per dwelling refurbished. Again, the fractions of waste going to the different disposal routes follows the practice for construction waste:

Re-use	10%
Recycling	60%
Landfill	30%

G.10. Scenarios for site excavation waste

Site excavation waste accounts for some 30 Mt of total C&DW waste (43%) using figures from the late 1990s (Howard 2000). This is equivalent to the mass of material from demolition. Uncertainty over the amount attributable to housing is very high. The figures quoted above refer to the total for the entire industry, and it seems likely that housing projects (especially smaller ones) will produce considerably less spoil than works carried out in other sectors – infrastructure, industry and commercial buildings. Each of these other sectors creates construction products on a larger scale than small housing projects and they are likely to produce a much larger quantity of excavation waste as a result. Not all housing projects are small, of course, and some are very large, with the ODPM's proposed development areas representing very large projects indeed.

In the absence of any better data, it is assumed that the site excavation waste from a dwelling is one-tenth of the mass of the building itself – ie 12 tonnes. On smaller projects, the figure will be smaller, but on large housing developments, the figure could be considerably higher: 12 tonnes is proposed as an average.

The definitions of re-use, recycling and landfill suggest that soil can only be re-used or landfilled. In effect, the only option is to bury it somewhere and the environmental impact is only lessened by using the excavation waste on-site, say as part of a landscaping plan. Recycling of excavation waste is possible in the production of earth bricks and rammed earth structures, where the clay content of the soil is within certain key boundaries. This potential is ignored in the modelling.

Scenario A

The figures follow the overall fractions estimated by Smith *et al* 2002, which are:

Re-use	20%
Recycling	0%
Landfill	80%

Scenario B

These values are set arbitrarily such that the three scenarios show a reasonable range of different options. The fractions for disposal routes are:

Re-use	50%
Recycling	0%
Landfill	50%

Scenario C

The fractions from scenario A are reversed – completely arbitrarily. The fractions for disposal routes are:

Re-use	80%
Recycling	0%
Landfill	20%

G.11. Summary figures

3.1 Total waste figures

Mass of waste (Mt)	to landfill	recycled	re-used	total per scenario	% increase over Scen A
Scenario A	5.9	1.7	0.6	8.1	
Scenario B	9.1	13.6	2.6	25.2	312
Scenario C	8.5	13.4	9.2	31.1	384

3.2 Construction & Demolition Waste Model – summary inputs

demolition waste per dwelling (t)		%ages				number demolished per year		mass (Mt)				% of scenario total
All scenarios	120	landfill	recycle	reuse			landfill	recycle	reuse	total		
		Scenario A	0.71	0.28	0.02	Scenario A	17000	1.4	0.6	0.0	2.0	30
		Scenario B	0.25	0.66	0.10	Scenario B	71000	2.1	5.6	0.8	8.6	36
		Scenario C	0.25	0.28	0.49	Scenario C	89000	2.7	2.9	5.2	10.8	36
construction waste per dwelling (t)		%ages				number built per year		mass (Mt)				% of scenario total
Scenario A	12	landfill	recycle	reuse			landfill	recycle	reuse	total		
Scenario B	9	Scenario A	0.7	0.27	0.03	Scenario A	169000	1.4	0.5	0.1	2.0	25
Scenario C	6	Scenario B	0.4	0.57	0.03	Scenario B	222000	0.8	1.1	0.1	2.0	8
		Scenario C	0.3	0.6	0.1	Scenario C	240000	0.4	0.9	0.1	1	5
refurbishment waste per dwelling (t)		%ages				number refurbished per year		mass (Mt)				% of scenario total
Scenario A	2	landfill	recycle	reuse			landfill	recycle	reuse	total		
Scenario B	12	Scenario A	0.7	0.27	0.03	Scenario A	1000000	1.4	0.5	0.1	2	30
Scenario C	16	Scenario B	0.4	0.57	0.03	Scenario B	1000000	4.8	6.8	0.4	12	50
		Scenario C	0.3	0.6	0.1	Scenario C	1000000	4.8	9.6	1.6	16	53
site excavation waste per dwelling (t)		%ages				number built per year		mass (Mt)				% of scenario total
All scenarios	12	landfill	recycle	reuse			landfill	recycle	reuse	total		
		Scenario A	0.8	0	0.2	Scenario A	169000	1.6	0	0.4	2.0	30
		Scenario B	0.5	0	0.5	Scenario B	222000	1.3	0	1.3	2.7	11
		Scenario C	0.2	0	0.8	Scenario C	240000	0.6	0	2.3	2.9	10

References

- CIBSE (1984) *CIBSE design guide*. Chartered Institution of Building Services Engineers, London, UK.
- Construction News website http://www.cnplus.co.uk/vital_statistics/industry_struct/ accessed 23 November 2005
- Defra (2003) *e-digest statistics*. Department for the Environment, Food and Rural Affairs, London, UK.
<http://www.defra.gov.uk/environment/statistics/waste/wrconstruc.htm>
- Howard N (2000) *Sustainable Construction – the data BRE client report CR 258/99*. available at <http://projects.bre.co.uk/sustainable/SusConstructionData.pdf> accessed 23 November 2005
- Ireland D (2005) *The greenhouse effect*. Society Guardian, The Guardian 5 May 2005
<http://society.guardian.co.uk/housing/story/0,7890,1476296,00.html>
- Jones, Craig (2005) *personal communication*. University of Bath
- Salvo website <http://www.salvo.co.uk/>
- Smith R, Kersey J and Griffiths P (2002) *The construction industry mass balance: resource use, wastes and emissions*. Viridis report VR4 published 2002, revised 2003
- Shorrocks LD and Utley JI (2003) *Domestic Energy Fact File 2003*. Building Research Establishment, Garston, UK.
- WRAP website <http://www.wrap.org.uk/publications/>